

BLACK & VEATCH

South Florida Water Management District  
**EAA Reservoir A-1 Basis of Design Report**

January 2006

**APPENDIX 8-1**

**EMBANKMENT TECHNICAL MEMORANDUM**

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TECHNICAL MEMORANDUM

South Florida Water Management District  
EAA Reservoir A-1  
Work Order No. 2

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**Task 16.18 Embankment Technical Memorandum**

To: Distribution

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**1. INTRODUCTION**

In October 2003, South Florida Water Management District (District) decided to pursue a “Dual Track” for the Everglades Agricultural Area (EAA) Reservoir project. While the multi-agency Project Delivery Team, lead by the US Army Corps of Engineers, continues to develop the Project Implementation Report, the District is proceeding with the design of a reservoir (designated EAA Reservoir A-1 Project) located on land acquired through the Talisman exchange in the Everglades Agricultural Area.

The EAA Reservoir A-1 Project is located in Palm Beach County. When completed it is expected to have a total storage capacity of approximately 190,000 acre-feet with a maximum water storage depth of approximately 12 feet. Actual storage depth will be defined through the design process.

The purpose of the Project as defined in the CERP is to capture EAA Basin runoff and releases from Lake Okeechobee. The facilities will be designed to improve the timing of environmental water supply deliveries to STA 3/4 and the WCA's, reduce Lake Okeechobee regulatory releases to the estuaries, meet supplemental agricultural irrigation demands, and increase flood protection within the EAA.

To proceed with implementation of the EAA reservoir, the District selected Black & Veatch from the General Engineering Services Contracts, Full Services to complete the 30% design services for the EAA Reservoir A-1 and associated pump stations.

This Embankment Technical Memorandum follows a Test Cell Program which was implemented to provide information for the Engineer to develop seepage modeling and embankment design criteria for the EAA Reservoir A-1.

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A detailed breakdown of the objectives is listed below:

- To evaluate the effectiveness a foundation cutoff in controlling seepage below the dam, by constructing two embankment designs, one with a cutoff and one without a cut-off.
- To explore the in-situ earth materials (local formations) and evaluate their use as embankment construction materials.
- To determine the embankment foundation treatment required during construction.
- To gain practical experience handling and placing the local earth materials in construction of the embankments allowing the assessment of the requirements and techniques necessary to optimize construction of the EAA Reservoir A-1.
- To obtain data to define the hydraulic conductivity of the local formations (less than 100 feet depth) to be used in estimating the total seepage from the EAA Reservoir A-1.
- To obtain data on construction production rates and costs.
- To evaluate the quality of materials from the Fort Thompson Formation limestone caprock for use in riprap, soil cement, and roller compacted concrete.
- To evaluate the production of erosion protection materials (riprap) from the Fort Thompson Formation limestone caprock.
- To evaluate the quality and processing requirements of crushed rock construction materials (embankment filter and drain) from the Fort Thompson Formation limestone caprock

Other results from the Test Cell Program are reported in Reservoir Seepage Analysis Technical Memorandum, Test Cell Construction and Seepage Monitoring Report, Reservoir Configuration Memorandum, and the Seepage Control Technical Memorandum. These Technical Memoranda have been developed in parallel and this Memorandum does not describe or include the recommendations described in the others. The next stage of the design process will bring the different facets together in a single recommended design solution.

## **2. OBJECTIVES**

The objectives of this Technical Memorandum are to:

- Develop alternative dam cross-sections for the EAA Reservoir A-1 using evaluation of seepage monitoring, observations and results of the Test Cells construction trial.
- Report on stability and seepage analyses conducted to evaluate alternative dam cross-sections.
- Report on evaluation of alternative dam sections with regard to cost and constructability.
- Summarize the recommended characteristics of the Reservoir A-1 dam cross section to be considered in the next stage of the design process.

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### **3. DESIGN CRITERIA**

#### **3.1 Sources**

United States Army Corps of Engineers (USACE) Design Manuals:

- Engineering Manual, EM 1110-2-1902, Engineering and Design: Slope Stability.
- Engineering Manual, EM 1110-2-2006, Roller-Compacted Concrete, 15 January 2000.
- Engineering Manual, EM 1110-2-2200, Gravity Dam Design, 30 June 1995.
- Engineering Manual EM 1110-2-2300, Earth and Rock-Fill Dams, General Design and Construction Considerations, 1 March 1971.

Acceler8 Design Criteria Team, Design Criteria Memoranda:

- ‘Hazard Potential Classification’, DCM-1, March 21, 2005.
- ‘Minimum Dimensions of Dams and Embankments’, DCM-4, March 21, 2005:
- ‘Geotechnical Seismic Evaluation of CERP Dam Foundations’, DCM-6, May 16, 2005.

From DCM-4:

- Based on the various agency guidelines, O&M considerations and constructability, the minimum crest width for CERP impoundments will be 14 feet for an embankment with 3H: 1V side slopes, as shown on Figure DCM 4-4 and described in the following section. The final design crest width is to be based on engineering analysis for seepage and slope stability requirements, analysis of the cost effectiveness for alternative embankment sections, and the constructability of the section.
- Based on experience, embankment slopes will be 3H: 1V or flatter, for the design of dams of the CERP projects to provide a suitable area for O&M activities, specifically mowing of the exterior slope. The final embankment slopes will be based on technical consideration of seepage and slope stability, erosion protection (due to wave action or surface runoff) and will be documented in the project Basis of Design Report.
- A Perimeter Access/Maintenance/Inspection Corridor (Perimeter Corridor) 50-foot wide is to be provided around the exterior perimeter toe of the embankment. The Perimeter Corridor is to include an 18-foot wide all-weather (gravel) surfacing. An interior corridor (Interior Corridor) 50-feet wide is to be provided around the interior to allow access when the reservoir is drained.
- The Exterior Perimeter is to consist of a clear, even graded area for dam safety inspection, but can also be used for maintenance and access to the dam and canals, and utilities on a select basis.

Acceler8 Design Criteria Team, ‘Hazard Potential Classification’, March 21, 2005.

#### **3.2 Material Parameters**

The parameters used in the preliminary stability analysis are listed in Table 1. The preliminary stability analyses were performed to determine limiting stability conditions using conceptual

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dam sections. The material parameters were selected based on engineering judgment developed through experience with similar materials on other projects. The effects of the RCC armored slope and the drain material were not considered in the embankment stability analysis. The RCC layer on the upstream slope would enhance slope stability. Therefore, ignoring it is conservative. The filter layers are narrow and of at least equal strength to the adjacent soil zones in the embankment. Therefore, ignoring the filter simplified the modeling effort without detriment to the results.

The soil and rock material types listed in the table below were obtained from the test cell embankment construction. These materials were derived from the Fort Thompson Formation and required various degrees of sorting and processing. A discussion of the subsurface stratigraphy as well as material types used in the test cell embankment construction is contained in the Test Cell Construction and Seepage Monitoring Report.

### **3.3 Embankment Dam Slope Stability Factor of Safety (FoS)**

The minimum required factors of safety for each embankment dam design case are as follows:

<b>Design case</b>	<b>Factor of safety</b>
End of construction	1.3
Steady seepage at normal pool level	1.5
Steady seepage with surcharge pool	1.3
Steady seepage with earthquake loading	1.1
Rapid drawdown from normal pool	1.3
Rapid drawdown from surcharge pool	1.1

### **3.4 Gravity Section Stability Criteria**

The concrete gravity dam stability criteria are shown in Table 2.

### **3.5 Water Levels**

The EAA Reservoir A-1 will be formed by a perimeter dam. Except for direct rainfall all water stored in the reservoir is pumped in from adjacent canals.

This Technical Memorandum assumes a normal operating water level (NWL) of 12 feet depth above existing ground (OG). The NWL is EL. 22.0 based on an assumed average ground surface elevation of 10 feet (NGVD).

The maximum hazard classification of this reservoir requires that the dam be sized to store the Probable Maximum Precipitation (PMP). The total dam height will depend on the normal water level plus the freeboard requirements. Freeboard allowance is determined from the effects of wind and rainfall and other considerations. Initial calculations for wave run-up, wind set-up and the effects of internal breakwaters were made in a previous work order and are described in Work Order No.3, Technical Memorandum 4 (Appendix 5-13 of the BODR).

The cases evaluated in that work included an extreme wind condition with no rainfall and a category 2 hurricane combined with the Probable Maximum Precipitation (PMP). The PMP was determined as part of Work Order No. 5. Freeboard requirements including allowances for

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rainfall, wave run-up and wind set-up were calculated for several alternatives of embankment slope, surface roughness, and fetch length. For the conditions initially modeled, the required embankment height, measured from the bottom of the reservoir to the top of the embankment, ranged from 29 to 36 feet without internal breakwaters and from 22 to 28 feet with internal breakwaters.

After the initial modeling was conducted, Design Criteria Memorandum DCM-2, Wind and Precipitation Design Criteria for Freeboard, was received from the District. Refined conditions are being evaluated under Work order No. 5. Preliminary results indicated that the required dam height to accommodate the required freeboard would range from about 25.7 to 31.4 feet depending on the slope and surface roughness selected. The 25.7 feet height is for earthen embankment sections evaluated in this technical memorandum. The 31.4 height is for the RCC section indicated in Embankment Alternative No. 5. Because the modeling is not yet complete, these results may change slightly as the work is completed and additional conditions are considered.

A PMP of about 4.5 feet was used as the basis for this memorandum.

### **3.6 Seismic Loading**

A pseudo-static horizontal coefficient 0.05 g and a simultaneous vertical acceleration of one-half the horizontal acceleration was used for the seismic analysis condition. A pseudo-static method of stability analysis was used because the reservoir site is in an area of low seismicity. The value chosen for the analysis are considered to be conservative given the low seismicity of the site.

### **3.7 Exterior Slope and Erosion Protection**

An exterior slope of 3 horizontal to one vertical 1 vertical (3:1) was used as the basis for the earth/rockfill embankment alternatives in accordance with the Acceler8 Design Criteria Team, 'Minimum Dimensions of Dams and Embankments'. Vegetative slope protection for the exterior slope is anticipated. The erosion protection for the exterior embankment slope will be discussed in more detail in the Basis of Design Report.

### **3.8 Embankment Top Width**

The embankment top width is 14 feet in accordance with the Acceler8 Design Criteria Team, 'Minimum Dimensions of Dams and Embankments'.

## **4. FOUNDATION CONDITIONS**

This Technical Memorandum is based on the subsurface conditions encountered at the test cell site and available borings completed by others on the reservoir perimeter. An additional investigation will be performed on the Reservoir A-1 site to better characterize the subsurface conditions and significant variations along the embankment alignment. A discussion of the subsurface conditions encountered at the test cell site is contained in Test Cell Construction and Seepage Monitoring Report.

## **5. DAM ELEMENTS AND AVAILABLE MATERIALS**

### **5.1 General**

The economic feasibility of the Reservoir A-1 project is dependent on effective utilization of available on-site materials in the reservoir construction. The development of the test cells and perimeter seepage collection canal allowed an evaluation of the suitability of on-site materials

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for embankment construction and slope protection. The proposed seepage collection canal on the exterior of the embankment is a source of embankment construction material. Additional embankment materials will be obtained from borrow areas excavated in the reservoir interior. Materials imported from offsite required for embankment construction could include bentonite and cement.

### **5.2 Core**

#### **5.2.1 General**

The primary purpose of a dam is to retain water thus the watertight element is the most important part of the dam. The other elements serve to ensure its long term stability under various conditions such as structural loads, uplift pressures and internal erosion.

A variety of materials have been used for this component elsewhere but only a few are considered sufficiently promising for further evaluation at this site as discussed in the following sections. The primary material considered for core material is the silty sand soil from the Fort Thompson Formation.

Discarded options included a central concrete core, and a conventional concrete gravity dam

#### **5.2.2 Earthfill Core**

The Test Cell construction demonstrated the feasibility of constructing a zoned earthfill embankment with a select fill core using fine sandy silt/silty sand materials excavated from the Fort Thompson Formation.

This material generally was classified in the borings performed at the test cell site as silty sand with gravel. In-situ the material is relatively permeable in the horizontal direction due to bands of gravel and shells. However, when placed and compacted in the embankment these materials are sufficient to retain water under low head conditions.

#### **5.2.3 Geomembrane and Geocomposite Clay Liner (GCL)**

Geomembranes have been used extensively to form impermeable barriers in landfills, canals, wastewater and industrial waste lagoons, and in raw water storage reservoirs. Geocomposite clay liners (GCLs) have also been used as an alternative to geomembranes in some applications.

Possible geomembrane materials include polyvinyl chloride (PVC), high density polyethylene (HDPE), and polypropylene. Geomembranes are joined at the seams by heat welding. HDPE was used in the upstream slope of the Tampa Bay Regional Reservoir. Typically, the geomembranes would be installed by companies that specialize in liner installation. GCLs are joined at the seams by overlapping the panels. Granular bentonite is placed at the seams to form a seal. Geomembranes and GCLs can be used as barriers in dams to replace the select fill cores. The typical installation of a geomembrane is either on the upstream slope beneath the erosion protection layer or buried within the upstream portion of embankment. A geomembrane has been incorporated into the section for embankment Alternative No. 2.

### **5.2.4 Roller Compacted Concrete (RCC)**

Roller compacted concrete (RCC) serves as the watertight element in a RCC gravity dam. RCC has not been considered as a thin watertight membrane on the upstream face of an earthfill embankment because of the potential cracking that could form from both shrinkage and settlement.

### **5.3 Shoulder (Shell) – Rockfill**

The outer rockfill zones of zoned embankments provide the strength to ensure the embankment stability and are normally included when the appropriate materials are available. Both test cells No. 1 and No. 2 were constructed with rockfill zones. The rock fill zone in Test Cell No. 1 was located at the exterior slope of embankment and on the Test Cell No. 2 the rockfill was located on the interior slope. The rockfill was obtained from caprock/limestone blasted from the seepage collection canal excavation. More details on the rockfill are discussed in the Test Cell Construction and Seepage Monitoring Report.

### **5.4 Random Fill**

Random Fill is defined as material of uncontrolled gradation not critical to embankment performance from required excavations, or other sources, whose permeability and shear strength is not critical to embankment stability. The random fill for the test cell program was defined as material from the required seepage canal excavations free from organic material, clods, and rock pieces larger than 12 inches and material that is not select fill or rockfill.

### **5.5 Internal Drainage – Crushed Aggregates**

The vertical chimney and horizontal blanket drains in the embankment dam serve to control pore pressures and the location of the phreatic line within the embankment. Horizontal drains also intercept and collect seepage through the dam foundation. The purpose of the chimney drain is to intercept seepage through more permeable horizontal layers inherent in the embankment construction to prevent saturation of the downstream slope and exiting the downstream slope above the toe. Flow intercepted through the chimney drain is conveyed to the horizontal drain. Coarse and fine aggregates for use in the internal drainage system can be crushed and screened from the caprock/limestone layer. The grading of the material and thickness of the drains will be refined during the design phase; they must meet filter criteria with the surrounding materials and have sufficient hydraulic capacity to carry the expected flows.

### **5.6 Foundation Drainage**

The horizontal blanket drain in an embankment also intercepts seepage that emerges from the embankment foundation and excess seepage pressure along the foundation contact. When a dam is founded on a pervious foundation such as the caprock on the reservoir site, the blanket drain also serves to:

- Relieve uplift pressure caused by seepage
- Permit discharge of seepage water from the foundation
- Prevent piping of fines from the embankment and foundation
- Convey the seepage to the downstream (or exterior) toe of embankment slope.

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The horizontal blanket drain installed in each test cell was composed of a filter and coarser drain rock. The drainage from Test Cell No. 2 was collected in a perimeter toe drain pipe located near the exterior toe of embankment slope. Drainage from the toe drain was routed to two sumps were located on the east side of the test cell due to the contour on top of the existing caprock. The water collected in the sumps was pumped to the seepage collection canal. No toe drain was installed in Test Cell No. 1. The design approach for internal embankment drainage on Test Cell No. 1 was that the seepage from the horizontal blanket drain would flow into and through the porous rockfill. A small select fill berm was constructed outside the exterior toe of rockfill slope to direct the flow traveling through the rockfill to two drainage sumps. Foundation drainage details for the test cell embankment are discussed in more detail in the Test Cell Construction and Seepage Monitoring Report.

Foundation drainage may be required for a concrete gravity dam to enhance stability by reducing uplift pressures. Such drainage is often provided by using drains drilled in the foundation. Proper filtering is required to prevent loss of fines from the foundation materials.

### **5.7 RCC**

RCC has a history of use in the United States and world wide in the construction of gravity dams. RCC also is used for overtopping protection of existing dams and as wave protection for embankments. RCC's use as wave protection is discussed in paragraph 5.8. The caprock limestone at the site will be the source of the aggregate for RCC.

### **5.8 Wave Protection**

#### **5.8.1 5.8.1 Roller Compacted Concrete (RCC)**

Roller compacted Concrete is indicated as erosion protection on the interior embankment slope in embankment Alternatives No. 1, No. 2, and No. 3. Roller compacted concrete is also used in the entire gravity section in Alternatives No. 4 and No. 5. Therefore, in these two alternatives it serves both as structure of the embankment and as erosion protection. RCC may be installed on earthfill embankments by placing parallel to the slope, a method known as the plating method, or by placing in horizontal lifts adjacent to the slope. The installation procedure selected is generally by the design requirements for the roughness related to wave run-up. The maximum slope inclination for the plating placement method is generally controlled by the slope angle a self-propelled roller can negotiate without shearing the RCC surface while providing adequate compaction. A 3:1 slope is generally recognized as the steepest slope upon which RCC can be installed by the plating placement method. When placed in horizontal lifts the typical width of lift is 8' to 10'. The minimum placement width is generally as dictated by the placement and compaction equipment. The horizontal lift is typically placed using a spreader box behind a dozer.

#### **5.8.2 Soil Cement**

Soil cement has been used as wave protection of embankment dams and levees in the United States. Soil cement is installed on embankments by placing parallel to the slope using the plating method as described for RCC or by placing in horizontal lifts adjacent to the slope. When placed in horizontal lifts the typical width of lift is 8' to 10'. Soil cement is placed by the same methods as described for RCC. The material for soil cement is typically a sand with non-plastic fines (percent passing the No. 200 sieve). A fines content of 35 percent is typically the maximum preferred for use in soil cement.

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### **5.8.3 Riprap**

Riprap is commonly used for slope protection when an economic source of suitable rock is available. The rock source must be capable of producing pieces of appropriate size to withstand the design wave action and have suitable durability characteristics.

The caprock was evaluated during the test cell construction for its use as riprap. The evaluation consisted of gradation tests performed on four different blasting trials and rock quality testing. A review of the gradations produced indicates that the caprock may not produce riprap that is sufficiently large for the design wave height for the project. For this reason none of the embankment alternatives consider riprap as the wave protection for the interior reservoir slope for this TM.

### **5.8.4 Precast Mass Concrete Crest Wall**

A precast concrete crest wall in the upper portion of the embankment could potentially be combined with some of the above wave protection alternatives to reduce embankment volume. The cost of embankment volume saved would need to offset the cost of the crest wall.

## **6. ALTERNATIVE DAM SECTIONS**

### **6.1 General**

This section of the Technical Memorandum describes the features of each of the dam sections which have been selected for preliminary evaluation in this Technical Memorandum. Some of the features are interchangeable between sections and design development will lead to refinements. All the sections except Embankment Alternative No. 6 were developed in the embankment workshop. Alternative No. 6 was developed in the process of drafting this technical memorandum. Embankment Alternatives No. 1 through No. 5 were selected for technical and cost evaluation. Embankment Alternative No. 6 applies only to the portion of the perimeter where the reservoir embankment of the EAA Reservoir A-1 parallels the existing Feeder Canal.

Embankment Alternatives No. 7, 8, 9, and 10 resulted from the embankment workshop but were not evaluated. These alternatives are discussed briefly in at the end of this section.

Alternative No. 11 was added following the Criteria Committee Meeting held June 20 – 22, 2005.

The embankment alternatives are illustrated in the figures at the end of this Technical Memorandum.

### **6.2 Embankment Sections – Embankment Alternatives No. 1, No. 2, and No. 3**

#### **6.2.1 Embankment – Upstream Rockfill with Central Seepage Detention Zone**

##### **6.2.1.1 General Description**

This embankment concept has been developed to utilize materials from the required seepage collection canal excavations and to minimize sorting and processing of these materials. The

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alternative is shown in Figure 1. The upstream rockfill zone materials will be produced from the caprock. Between the rockfill and random fill zones, a layer of transition material, will protect against migration of fines from the random fill material zone (maximum 6 inch size to minus No. 200 sieve) into the rockfill by action of gravity, during drawdown and the water level change that the embankment will experience. The top of the rockfill and random fill (max size 6") seepage detention zone will be limited to the elevation of the normal water level (NWL) plus the PMP allowance. Based on observations made during the Test Cell Program, the random fill placed at levels above the seepage detention zone will be sufficient to control transient wetting caused by waves above that level.

A vertical filter (chimney drain) is provided for internal drainage, to protect against internal erosion of the fines within the random fill, and to control the phreatic line in the downstream slope. The filter gradation and its width will be selected to ensure sufficient capacity to eliminate the need for a two material filter/drain system.

A horizontal blanket filter extends over the caprock to relieve seepage pressures, control loss of material from the foundation and carry seepage intercepted in chimney to d/s toe. A triangular profile toe drain is provided at the outside toe of embankment. Finger drains may be used to connect the horizontal blanket filter to the triangular profile toe drain.

The downstream slope of the embankment will be seeded and placed at 3H to 1V to allow for maintenance as required by the District design criteria.

### **6.2.1.2 Advantages**

The advantages of this design include:

- Efficient use of pre-excavation of seepage collection canal.
- Requires minimal sorting of excavation and borrow materials.
- The construction process for the inclined core has been tested during the test cell program and found to be effective.
- No special treatment of the caprock is required apart from power brushing.
- The seeded downstream slope blends in with the general surroundings and adds aesthetic value.
- Apart from the cement for the wave protection and bentonite for the cut-off wall, dam construction materials are available and can be produced on site
- Processing of excavated material is limited to crushing, screening, washing, and blending for filter and drain materials, and crusher run production of the transition material.
- The embankment has the flexibility to accommodate settlement in the foundation.
- Earthfill embankments are very resilient to earthquake loading.
- Provides increased protection against potential of dam breaks; mitigates impact.

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### **6.2.1.3      *Disadvantages***

The disadvantages of this design include:

- Limiting the seepage detention zone to maximum 6" particle size requires designated equipment for raking and removing oversize from the random excavation materials; represents a cost impact.
- This design does not lend itself well to increasing the height of the dam.

### **6.2.2      *Embankment with Geomembrane***

#### **6.2.2.1      *General Description***

This embankment contains a sloping geo-membrane embedded within the upstream interior zone of the embankment (See Figure 2). At the bottom of embankment, the membrane is horizontal and is placed over the top of the cut-off wall. Silty sand material (Select Fill as in Test Cell Program) can be used for geomembrane embedment. The membrane could consist of a geomembrane or a geocomposite clay liner (GCL). A random fill zone is placed on the exterior embankment side of the membrane. The membrane is separated from the random fill zone with a layer of select fill and a transition material layer. A horizontal blanket drain composed of a fine aggregate filter and a granular drain is included to collect potential leakage through the membrane and seepage from the caprock foundation. The drainage from the filter is conveyed to the outside embankment toe through finger drains.

#### **6.2.2.2      *Advantages***

The advantages of this design include:

- The construction process for the inclined select fill zone has been tested and proven effective during the test cell program.
- Because of the combined select fill zone and membrane, seepage through the embankment will be small. Therefore, a chimney filter drain is not required.
- No special treatment of the caprock is required apart from power brushing.
- The seeded downstream slope blends in with the general surroundings and adds aesthetic value.
- Apart from the cement for the wave protection, bentonite for the cut-off wall, and the geomembrane, embankment construction materials are available and can be produced on site.
- The embankment can accommodate settlement in the foundation.
- Processing of excavated material is limited to production of filter and drain materials, and the crusher-run transition material.

#### **6.2.2.3      *Disadvantages***

The disadvantages of this design include:

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- Controlled placement of the embankment fill zones is required to limit geomembrane movement.
- Geotextile or cushioning soil is required on both sides of the geomembrane to prevent damage by rocks in the embankment fill.
- Connecting geomembrane to any required cutoff wall for seepage control requires special detailing and installation to ensure long-term stability of the geomembrane/cutoff interface.
- The section represents added project cost with no apparent seepage control advantage considering the low-head project design. (The geomembrane offers no advantage as a water barrier because the adjacent select fill zone effectively serves that purpose.)
- Construction sequencing is complicated by placement and protection of the membrane.
- Controlling the maximum particle size of fill placed against the membrane requires screening.

### **6.2.3     *Embankment – Central Water Detention Zone and Shallow Foundation Cutoff Trench***

#### **6.2.3.1     *General Description***

This embankment section (Figure 3) has been developed to utilize a select fill central zone for seepage control through the embankment. In the embankment, the seepage detention zone is stabilized by random fill zones. A zone of transition material is placed above the select fill and extends along the interior slope between the RCC erosion protection and the random fill zone.

A trench extending through the caprock and into the foundation silty sand is provided to prevent seepage primarily through caprock. The minimum width of the key trench is governed by the hydraulic gradient across the base of the trench. Additional protection of the fill against piping would be required on the sides of the trench because of potential open areas or voids and channels through the caprock. This protection can be provided by shotcreting the inclined slope through the caprock.

#### **6.2.3.2     *Advantages***

The advantages of this design include:

- No special treatment of the caprock is required apart from power brushing
- The seeded downstream slope blends in with the general surroundings and adds amenity value.
- Apart from the cement for the wave protection and bentonite for the cut-off wall, all materials are available and can be produced on site.
- Processing of excavated material is limited to crushing, screening, washing, and blending for filter and drain materials, and selection on the embankment for the transition material between core and rockfill shoulder.
- The embankment can accommodate settlement in the foundation.

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- Earthfill embankments are very resilient to earthquake loading
- Provides protection against piping through the caprock

### **6.2.3.3      *Disadvantages***

The disadvantages of this design include:

- Trench excavation, shotcreting, and backfill placement requires dewatering.
- Production of the select fill material from the excavations requires separate stockpiling of wet material.
- The top of exterior zone of random fill is narrow and difficult to place with typical earthmoving equipment
- Large volume of processed transition material required.
- Without a cutoff wall, a high seepage gradient will develop below the base of the cutoff trench creating a high risk or potential for piping.

## **6.3      *Roller Compacted Concrete (RCC) Dam Sections***

### **6.3.1      *Roller Compacted Concrete (RCC) Dam – Original USACE Design***

#### **6.3.1.1      *General Description***

The roller compacted concrete gravity dam section depicted in Embankment Alternative No. 4 (Figure 4) was developed by the Jacksonville District, USACE. It is composed of three stepped RCC sections with a vertical face on the interior of the reservoir embankment. The aggregate for RCC would be obtained from onsite caprock/limestone materials excavated from the seepage collection canals and borrow areas within the reservoir interior.

#### **6.3.1.2      *Advantages***

The advantages of this design include:

- Occupies less area (smaller footprint) than an embankment dam; reservoir storage can be maximized.
- A single material-type is used in construction.
- Maintenance of the downstream slope should be minimal.

#### **6.3.1.3      *Disadvantages***

The disadvantages of this design include:

- The RCC gravity dam requires a firm, unyielding foundation. A gravity dam is more sensitive to local variations in the caprock quality and thickness due to the smaller footprint and unit loading. Thinner or non-existent caprock layers could result in higher total and differential settlement.
- Increases foundation cleaning and treatment requirements and costs.
- Experience with test cell construction indicates that the blasted rock is mixed with underlying silty sand requiring extensive processing to separate usable rock.

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- A larger volume of cement required and would need to be imported.
- The pre-excavation of the seepage canal becomes less attractive an option because caprock used for RCC aggregate production would need to be hauled to aggregate processing areas increasing the cost of RCC production.
- Silty sand from seepage collection canal excavation would be excess material not required for the dam construction.
- Special foundation treatment measures would be required where caprock does not exist or where it is thin.
- A concrete dam would not fit aesthetically with the surroundings.
- Seepage of leakage along lift lines would quickly lead to vegetation growth which would be unsightly and lead to maintenance problems
- A steep or vertical upstream face has safety implications because it creates a fall hazard, especially when reservoir has a low water level, and the vertical inside face offers no means for escape for anyone falling into the reservoir when it contains water. (These safety issues could be mitigated by installing fencing around the reservoir and ropes or ladders on the vertical inside RCC face)

### **6.3.2 Roller Compacted Concrete (RCC) Dam – Alternative**

#### **6.3.2.1 General Description**

The embankment Alternative No. 5 (Figure 5) is a RCC gravity dam section with stepped interior and exterior dam faces. The aggregates for the RCC dam would be produced from onsite materials excavated from the seepage collection canals and borrow areas excavated within the reservoir interior.

This dam section was evaluated to potentially reduce the forming costs for an RCC dam and to provide a broader footprint for distributing contact stresses.

#### **6.3.2.2 Advantages**

The advantages of this design include:

- Occupies less area than an embankment dam, thereby increasing reservoir storage potential.
- Stepped inside slope minimizes safety issues.

#### **6.3.2.3 Disadvantages**

The disadvantages of this design include:

- Increased foundation cleaning and treatment requirements over those for an embankment dam.
- Experience with test cell construction indicates that the blasted rock is mixed with underlying silty sand requiring extensive processing to separate usable rock from the soil.

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- A concrete dam is sensitive to the condition of the foundation. With a smaller footprint than an embankment, a gravity dam would be more sensitive to local variations in the caprock.
- Special foundation treatment measures would be required where caprock does not exist or where it is thin.
- A concrete dam would not fit aesthetically with the surroundings.
- Seepage along lift lines and joints would lead to vegetation growth which would be unsightly and may develop into maintenance problems.

### **6.4 Embankment Section along STA 3/4 Supply Canal**

#### **6.4.1 General Description**

The embankment section depicted in Alternative No. 6 represents an embankment alternative to accommodate the existing seepage canal and perimeter levee for the STA 3/4 and Holey Land. If a buffer is maintained between the Reservoir A-1 embankment and the existing feeder canal, then Embankment Alternatives No. 1 through No. 5 could be considered. A total random fill embankment section has been shown for this alternative (Figure 6).

#### **6.4.2 Advantages**

The advantages of this alternative include:

- Less stripping of peat required
- Embankment section simplified; no separation of excavated materials required for construction
- Caprock excavation not necessary for construction of key trench or a cutoff wall installation.
- Existing seepage collection canal may be used for key trench type of foundation cutoff through the caprock.
- Reduced embankment volume because outside slope is constructed against the existing perimeter levee of the feeder canal.
- Existing perimeter levee can be used as access road.
- Cutoff wall could be constructed in area of existing seepage collection canal eliminating the need for caprock removal

#### **6.4.3 Disadvantages**

The disadvantages of this method include:

- Seepage into STA 3/4 seepage canal and feeder canal would be uncontrolled.
- Dewatering required during fill placement in existing seepage canal.

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- Higher level of construction control for material mixing, placement, and compaction required to ensure adequate seepage detention function.
- Requires a higher degree of compaction control and density on the outer portion of the upstream slope to support placement of the slope protection.
- Increases the potential for long-term settlement of the slope protection due to the increased portion of fine-grained materials within the random fill matrix.
- Back-up protection for a breach in the slope protection is significantly reduced due to the high percentage of fines in the random fill.

### **6.5 Embankment Sections Not Evaluated**

Four embankment sections developed for the workshop were not considered in the evaluation. These sections were eliminated because they either did not meet initial scrutiny based on economy or did not use excavated materials efficiently.

#### **6.5.1 Select Fill/Random Fill Embankment**

Embankment Alternative No. 7 (Figure 7) contains a select fill zone forming the interior section and slope of the embankment with a random fill zone comprising the downstream slope section and topping out of the embankment. This section was not considered for more detailed evaluation because it would require more significantly increased material processing and foundation preparation than other embankment alternatives utilizing the blasted caprock.

#### **6.5.2 Rockfill Embankment With Central Core**

This embankment uses a central select fill zone with the remainder of embankment composed of rockfill. The section was eliminated because it would not fully utilize the silty sand mixture with rock pieces readily available from the seepage collection canals. There is not enough rock from the seepage collection canal to construct this embankment. Supplemental borrow areas from within the reservoir would be required to provide additional rockfill. This results in a design more costly than the other alternatives.

#### **6.5.3 Homogeneous Embankment**

This embankment section was visualized as a homogeneous embankment of random fill. This embankment offers the simplest construction for fill placement. The embankment construction would require a relatively deep lift thickness to accommodate the blasted rock from the required excavations and borrow sources. The increased lift thickness and "random" gradation makes constructing the embankment to provide effective long-term water detention more difficult. Allowing large rock pieces in an embankment lift using materials containing a high percentage of fines generally results in decreasing the effective compaction and fill quality in the area surrounding the rock. Increasing the lift thickness to accommodate rock pieces will reduce the fill density in the fine-grained materials present at this site resulting in increased seepage potential and embankment settlement. This design would involve more processing of material to obtain a quality embankment for long-term performance than required in Embankment Alternative No. 1. Therefore, this alternative was not chosen for evaluation.

### **7. STABILITY ANALYSES**

#### **7.1 *Embankment Slope Stability Method***

Embankment stability analyses were performed using the computer program SLOPE/W, version 5.17, by GEOSLOPE International Ltd.

#### **7.2 *Material Parameters***

##### **7.2.1 *Alternatives Modeled***

Two alternative embankment cross-section models were analyzed to evaluate the slope stability. The two cross-sections selected (Model A and Model B) for stability are considered representative of the embankment Alternatives No. 1 to No. 3 and No. 6. It is believed by examination that the factors of safety for the cross-sections that were not analyzed are at least as large as those calculated for the two cross-sections analyzed. The geometry of the two cross-sections modeled are shown in Figures 12 and 13. Additional slope stability analyses will be performed in the BODR phase for the recommended alternative.

##### **7.2.2 *Results of Stability Analysis***

The results of the stability analysis are listed in Tables 3 and 4. The output from stability analyses are contained in Appendix 8-2 of the BODR. The results show embankments meet required factor of safety criteria except for the rapid drawdown conditions for Stability Model B. This unacceptable factor of safety for rapid drawdown indicates that the selected shear strength of the random fill is inadequate. The low factor of safety was as anticipated for the fill constructed of cohesionless soils with a cohesion value of zero and the assumption of an instantaneous drawdown without any drainage. The factor of safety can be improved by providing a zone of free draining rockfill between the RCC slope protection and the random embankment fill and taking into account the stabilizing effects of the RCC slope protection layer which was not modeled. This analysis indicates that the recommended cross-section should be based on the consideration of the rapid drawdown condition.

Stability Model B was modeled by ignoring the presence of the chimney drain and horizontal drainage blanket. This analysis also demonstrates that the outside embankment slope is stable without the effect of the chimney and blanket drains. While the stability is adequate without the chimney and blanket drains, the chimney and blanket drains or other zoning measures may still be a prudent solution to the internal erosion and piping failure concerns for an embankment consisting of predominantly silty sand.

#### **7.3 *Roller Compacted Concrete (RCC) Gravity Section***

##### **7.3.1 *Method***

The design basis for evaluation of the two alternative RCC sections was EM 1110-2-2006, Roller-Compacted Concrete and EM 1110-2-2200, Gravity Dam Design.

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### **7.3.2 Results**

The stability of Embankment Alternative No. 4 has been performed by the USACE and was not repeated and presented in this TM. The results of the analysis for Embankment Alternative No. 5 are listed Table 5. The stability calculations for Alternative No. 5 are contained in Appendix 8-3 of the BODR.

## **8. CONSTRUCTION COST CONSIDERATIONS**

Comparison costs were developed for each of the five selected embankment alternatives. These costs were developed considering factors such as material handling and processing requirements and construction efforts for the various material types discussed in this memorandum. These costs are described and given in Embankment Technical Memorandum II.

## **9. RECOMMENDATIONS**

The following recommendations are based on observations made during the test cell construction and seepage monitoring and subsequent evaluations. As discussed in more detail below, it is recommended that an embankment dam with internal drainage control and a cutoff wall be developed for the Reservoir A-1. It is recommended that during development of the Basis of Design Report additional opinions be solicited from earthmoving contractors on different methods and specialized equipment that could be employed in excavation and fill placement for construction of the A-1 Reservoir embankment.

### **9.1 Embankment**

The Reservoir A-1 embankment is considered a low head or small dam for design purposes. The cross section for an embankment for these design requirements only needs to employ zoning to the extent to efficiently utilize the excavated materials while providing the requirements for seepage control and stability. Zoning can be obtained by selective excavation and/or minimal material handling.

### **9.2 Internal Drainage**

It is recommended that the internal drainage be kept to simple details. Based on the low head conditions and moderately low permeability of the fill materials, a common filter for a chimney concept appears acceptable thereby eliminating the need for a two-stage filter as used in the test cell construction.

A horizontal filter placed over the caprock foundation downstream of the seepage detention zone and chimney is required to mitigate potential piping of fines from the foundation.

A horizontal drain section located over the downstream one-third of the foundation and filter is recommended to ensure positive drainage to the downstream toe and to mitigate saturation of the embankment fill.

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### **9.3 Wave Protection**

Wave protection on the inside embankment slope should be either roller compacted concrete or soil cement. The erosion protection on the outside toe of slope should be a layer of peat soil seeded or planted with native grass or a low maintenance ground cover.

### **9.4 Fill Material Excavation and Placement**

#### **9.4.1 Fill Material Excavation**

Based on the material excavation experience gained during the Test Cell Program and preliminary data on the subsurface conditions across the reservoir site, embankment materials required for rockfill and random fill zones can be readily separated into separate stockpiles. During the test cell construction, the contractor used hydraulic excavators to excavate and stockpile materials for drainage. All materials available for use in the dam construction will be excavated from below or nearly below the existing groundwater level. Embankment zoning will impact the selection of the most effective and economical means of excavation and stockpile placement.

#### **9.4.2 Fill Placement**

Drying or moisture reduction of the wet silty sand caused much difficulty during construction of the test cells. Recommendations for handling of the wet silty sand are discussed in the Test Cell Construction and Seepage Monitoring Report.

## **10. REFERENCES**

- United States Army Corps of Engineers (USACE) Engineering Manual, EM 1110-2-1902, Engineering and Design: Slope Stability.
- United States Army Corps of Engineers (USACE) Engineering Manual, EM 1110-2-2006, Roller-Compacted Concrete, 15 January 2000.
- United States Army Corps of Engineers (USACE) Engineering Manual, EM 1110-2-2200, Gravity Dam Design, 30 June 1995.

## Embankment Technical Memorandum

### TABLES

**Table 1 Parameters Used in the Preliminary Stability Analysis**

Material Type	$\gamma_T$ (pcf)	$\gamma_{SAT}$ (pcf)	$c'$ (psf)	$\phi'$ (°)	$c_T$ (psf)	$\phi_T$ (°)	Remarks
Rockfill	135	140	0	40	0	40	
RCC	145	150	5,000	35	5,000	35	Not modeled
Transition Zone	115	122	0	33	0	33	
Random Fill (6" max.)	115	122	0	33	0	33	
Random Fill	115	122	0	35	0	35	
Filter	120	125	0	35	0	35	Not modeled
Limestone	134	140	2,000	40	2,000	40	
Silty Sand with Gravel	120	125	100	33	100	33	
Gravelly Sand	120	125	0	35	0	35	

**Table 2 Concrete Gravity Dam Stability Criteria**

Load Condition	Location of resultant	Min FoS against sliding	Foundation bearing pressure	Concrete stress	
				Compression	Tension
Usual	Middle 1/3	2.0	= allowable	0.3 $f_c'$	0
Unusual	Middle 1/2	1.7	= allowable	0.5 $f_c'$	0.6 $f_c'^{2/3}$
Extreme	Within base	1.3	= 1.33 x allowable	0.9 $f_c'$	0.9 $f_c'^{2/3}$

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**Table 3      Stability Model A**

Case	Strength Parameters	Factor of Safety	
		Upstream Slope	Downstream Slope
End of Construction	Total	FS = 2.58	FS = 2.17
Steady Seepage with Normal Pool	Effective	-	FS = 1.92
Steady Seepage with Surcharge Pool	Effective	-	FS = 1.87
Rapid Drawdown from Normal Pool	Effective	FS = 1.41	-
Rapid Drawdown from Surcharge Pool	Effective	FS = 1.34	-
Steady Seepage with Earthquake Loading	Effective	-	FS = 1.75

**Table 4      Stability Model B**

Case	Strength Parameters	Factor of Safety	
		Upstream Slope	Downstream Slope
End of Construction	Total	FS = 2.18	FS = 2.17
Steady Seepage with Normal Pool	Effective	-	FS = 1.92
Steady Seepage with Surcharge Pool	Effective	-	FS = 1.87
Rapid Drawdown from Normal Pool	Effective	FS = 1.02	-
Rapid Drawdown from Surcharge Pool	Effective	FS = 0.98	-
Steady Seepage with Earthquake Loading	Effective	-	FS = 1.75

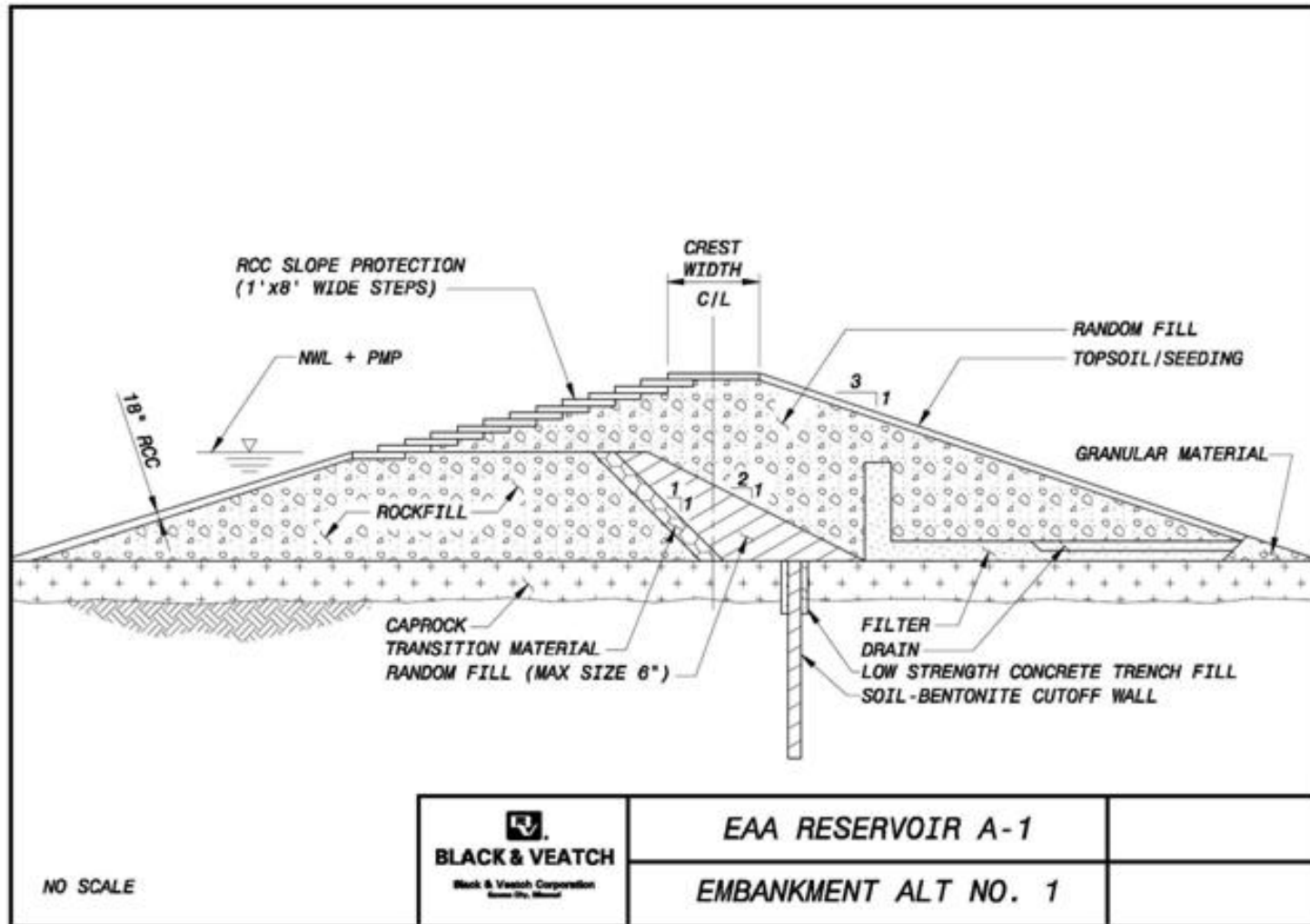
**Table 5      Embankment Alternative No. 5 Stability Results**

Embankment Alternative	Analysis Condition	Factor of Safety	
		Overturning	Sliding
No. 5	NWL	Resultant falls in middle 1/3	17.69
No. 5	PMP	Resultant falls within base	9.70
No. 5	NWL plus Seismic	Resultant falls within base	17.17

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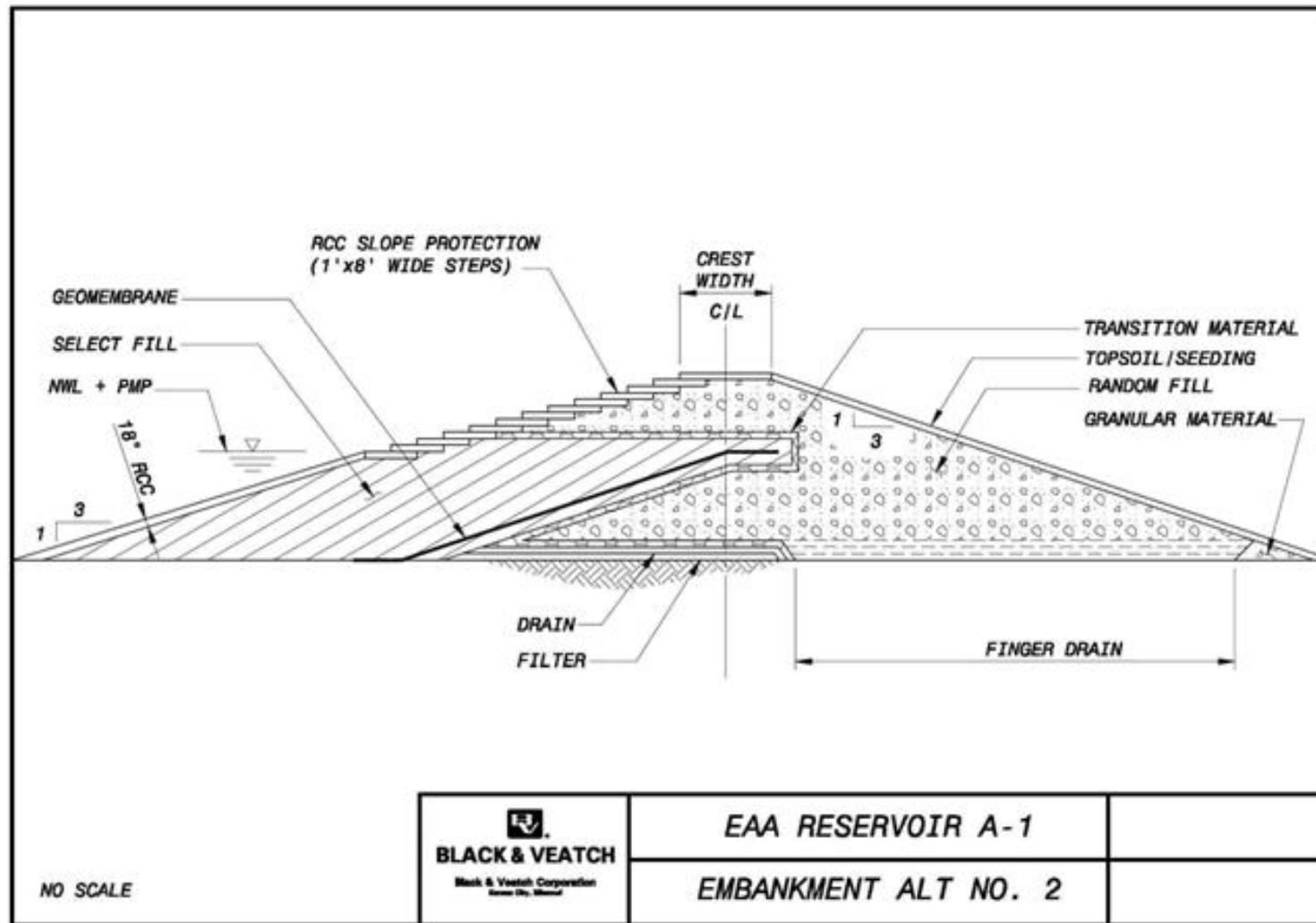
Figure 1

Embankment Alternative No. 1



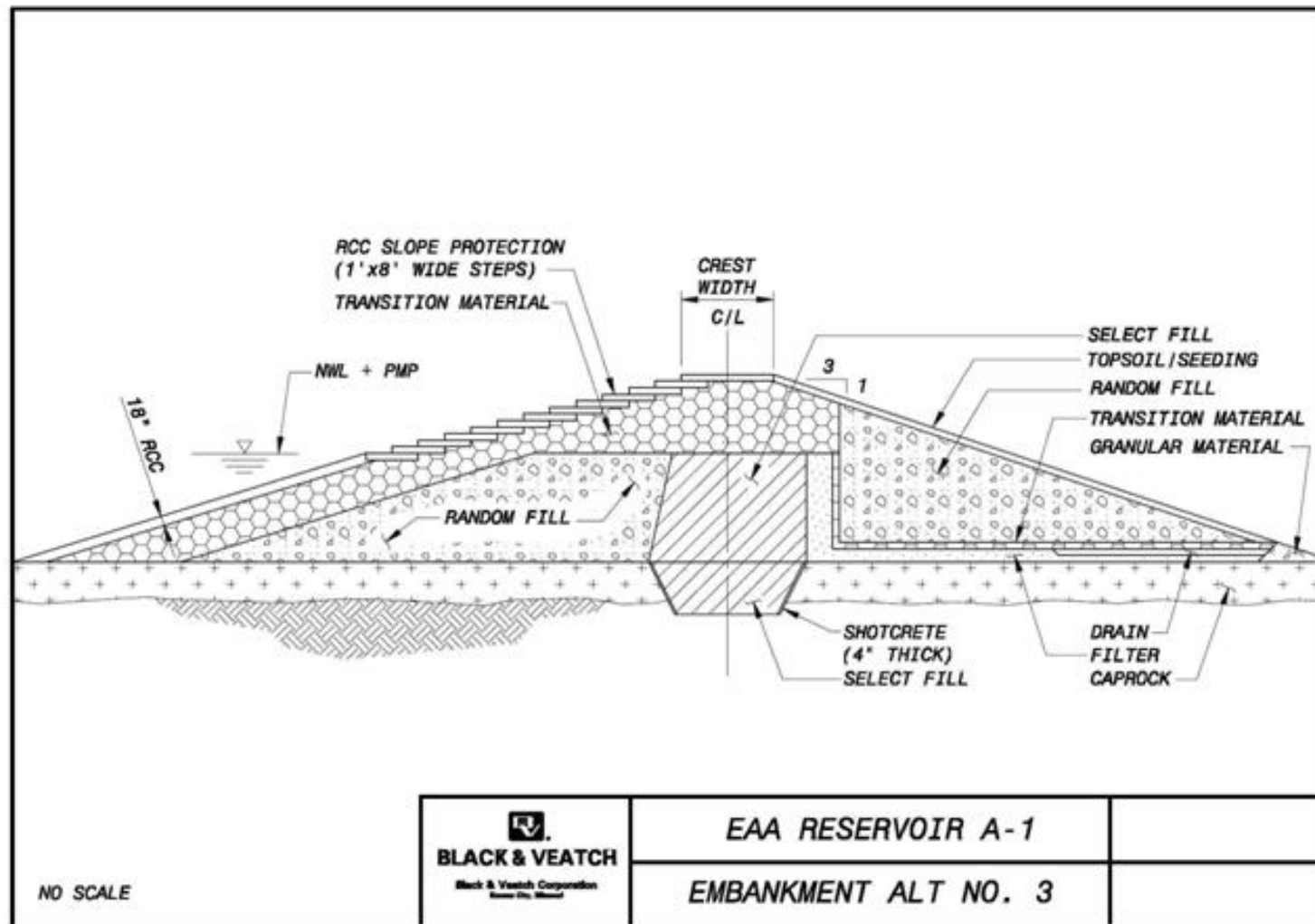
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Figure 2      Embankment Alternative No. 2



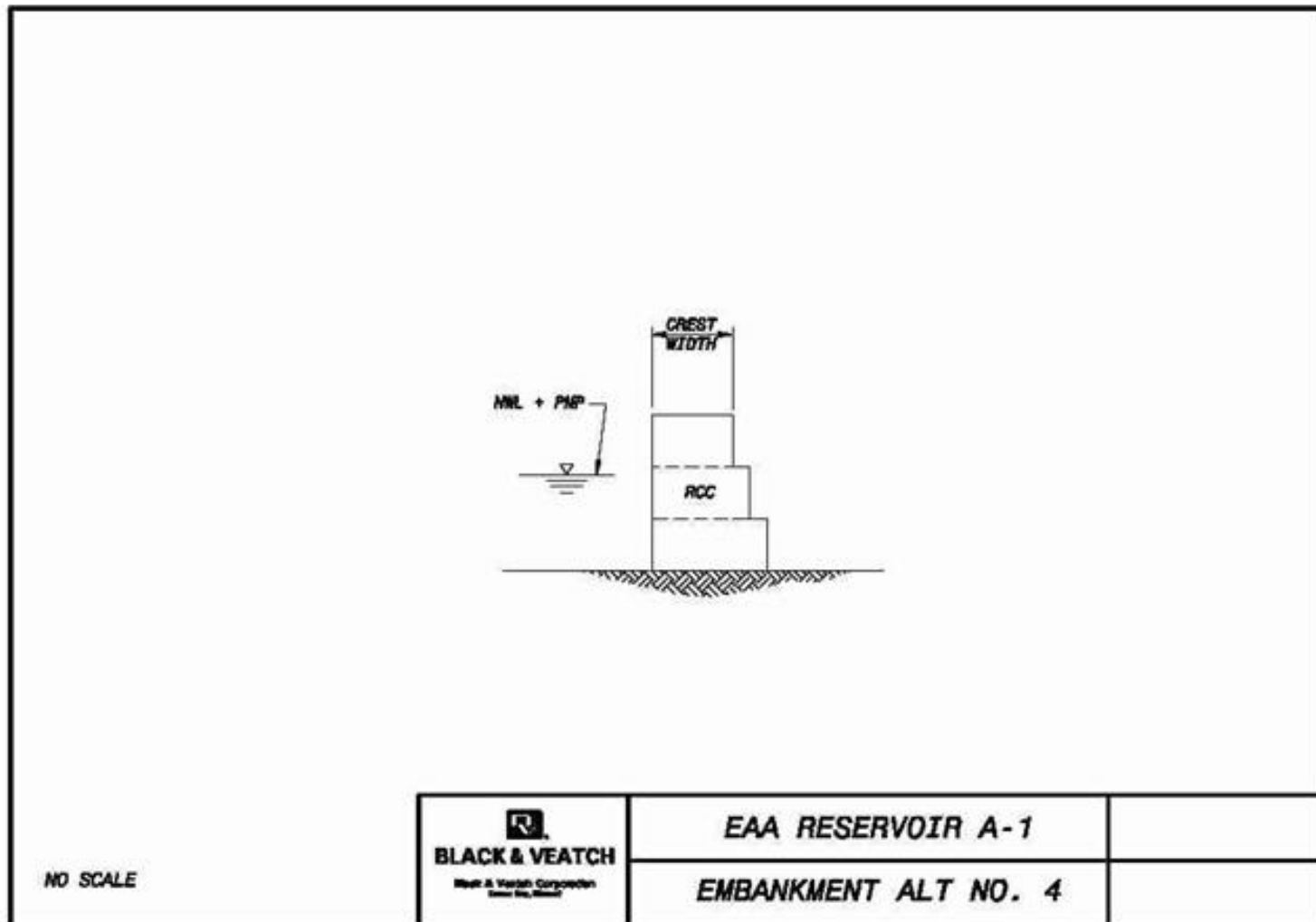
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Figure 3 Embankment Alternative No. 3



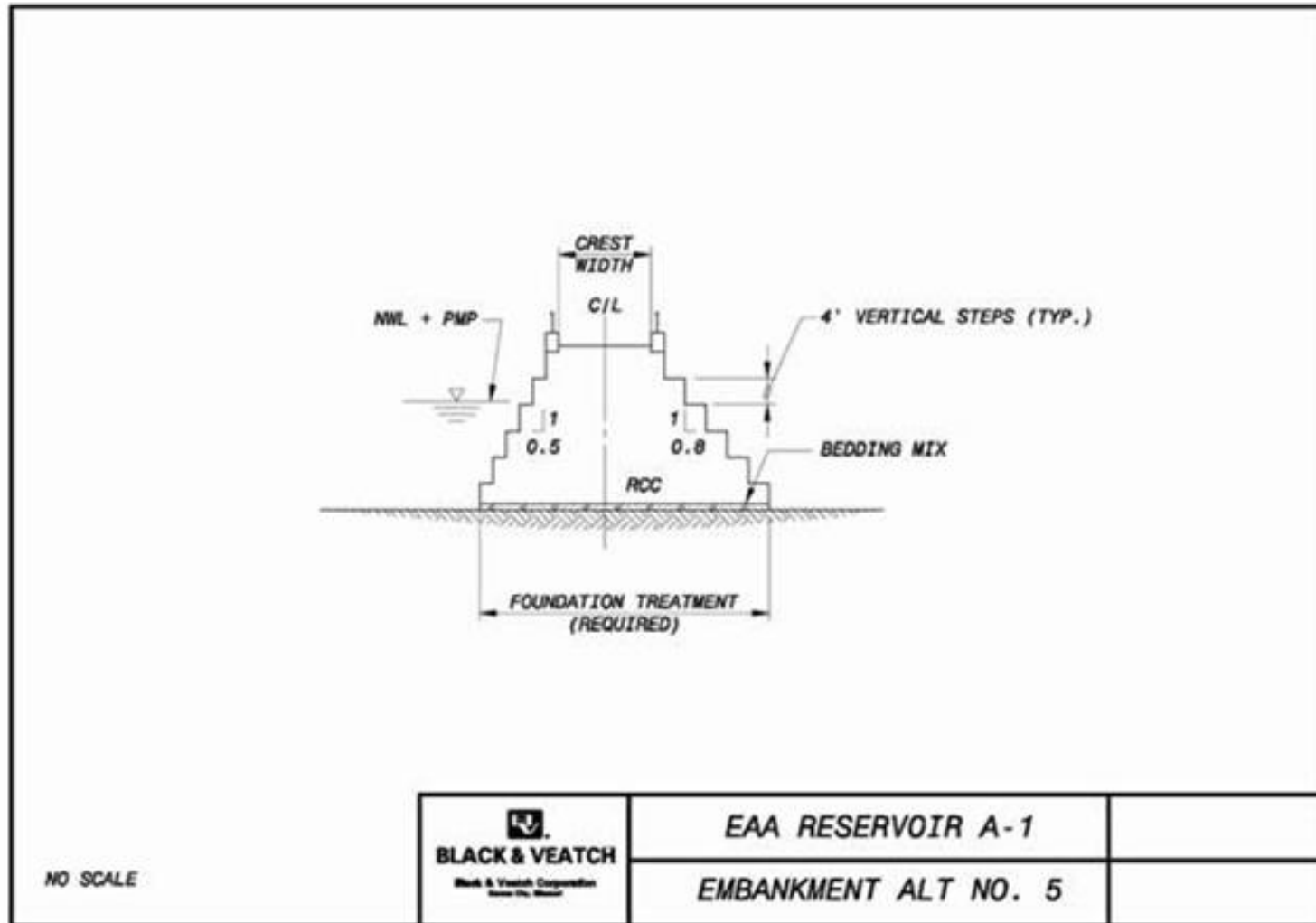
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Figure 4      Embankment Alternative No. 4



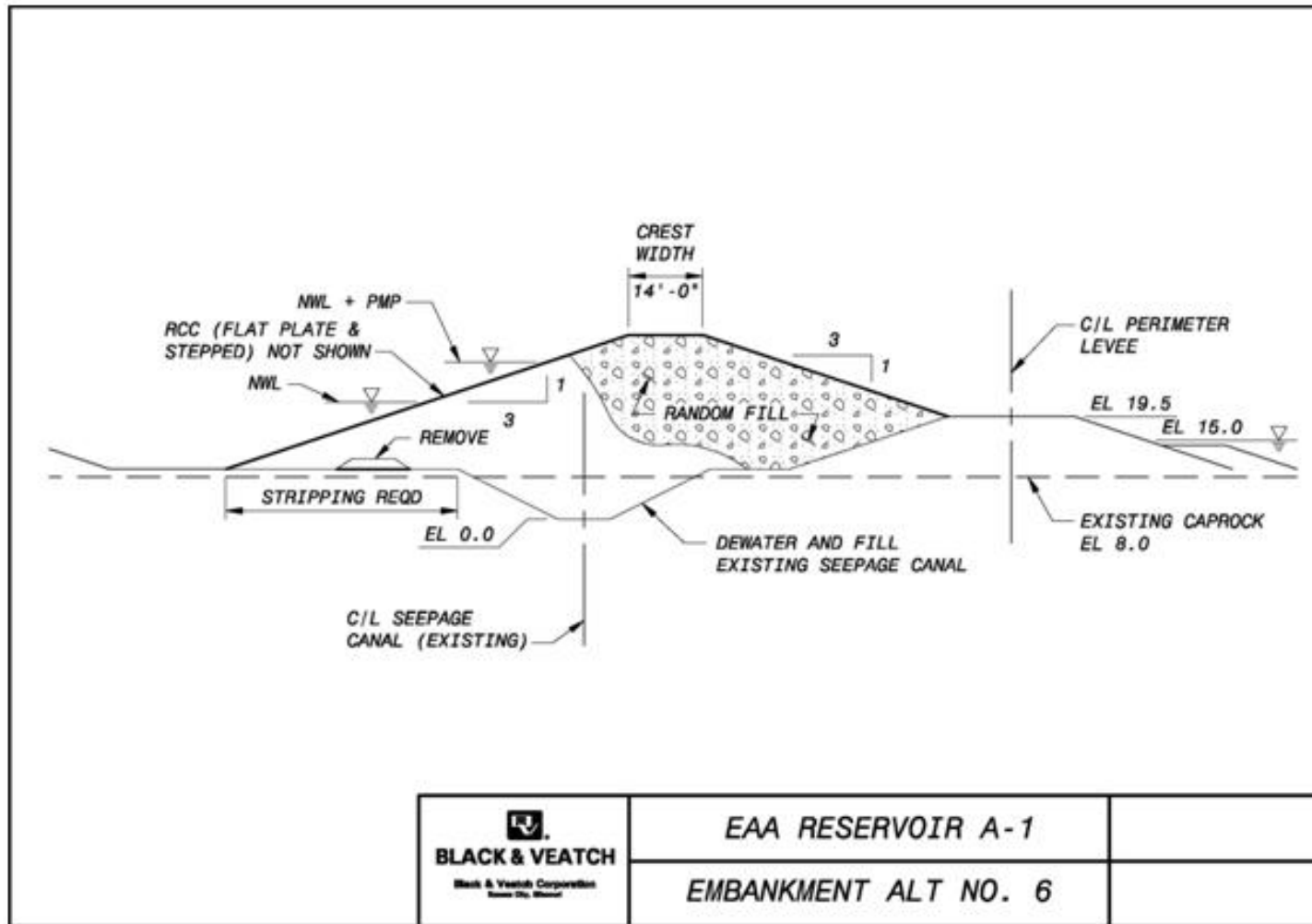
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Figure 5      Embankment Alternative No. 5



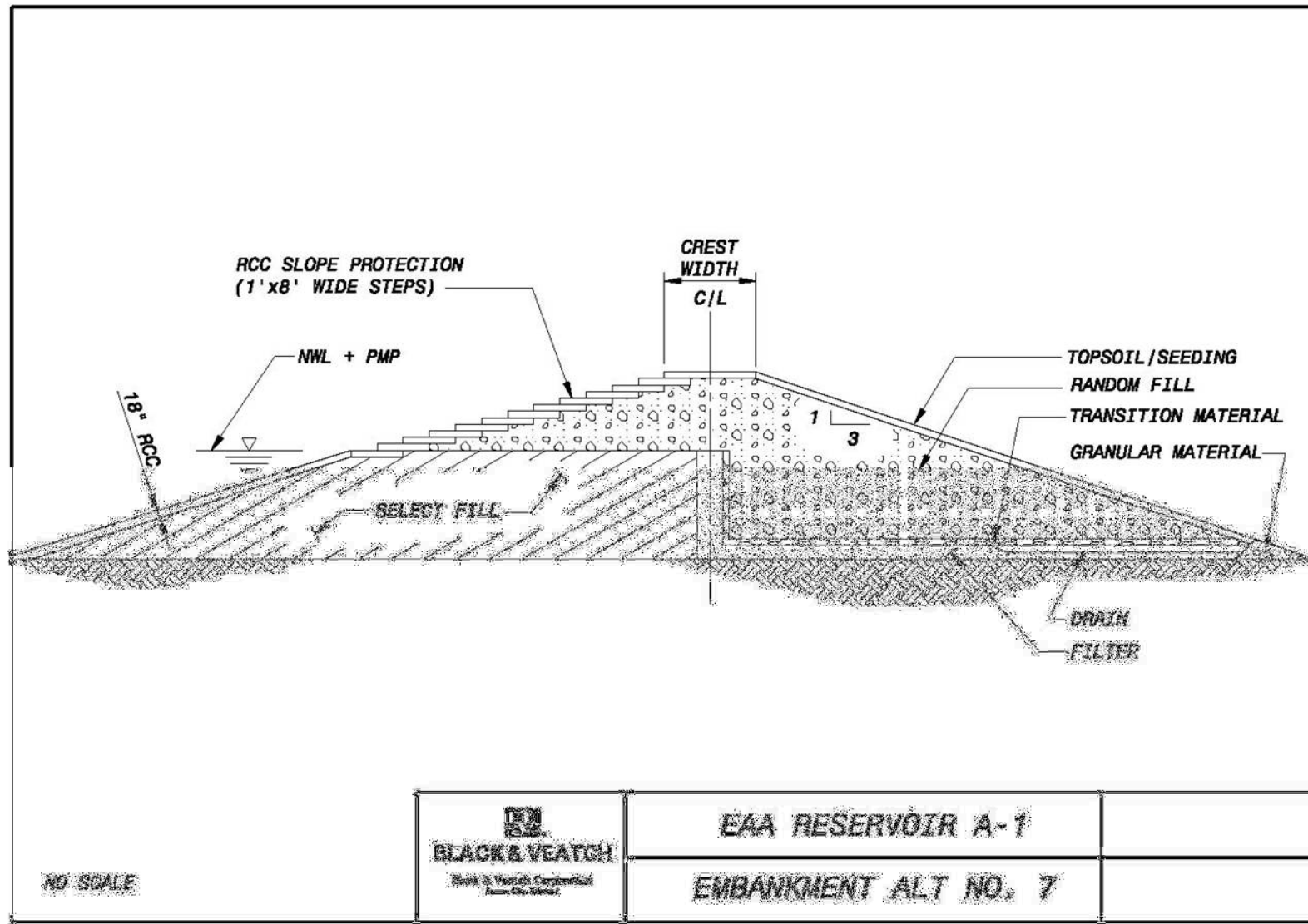
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Figure 6 Embankment Alternative No. 6



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Figure 7 Embankment Alternative No. 7



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Figure 8 Stability Model A

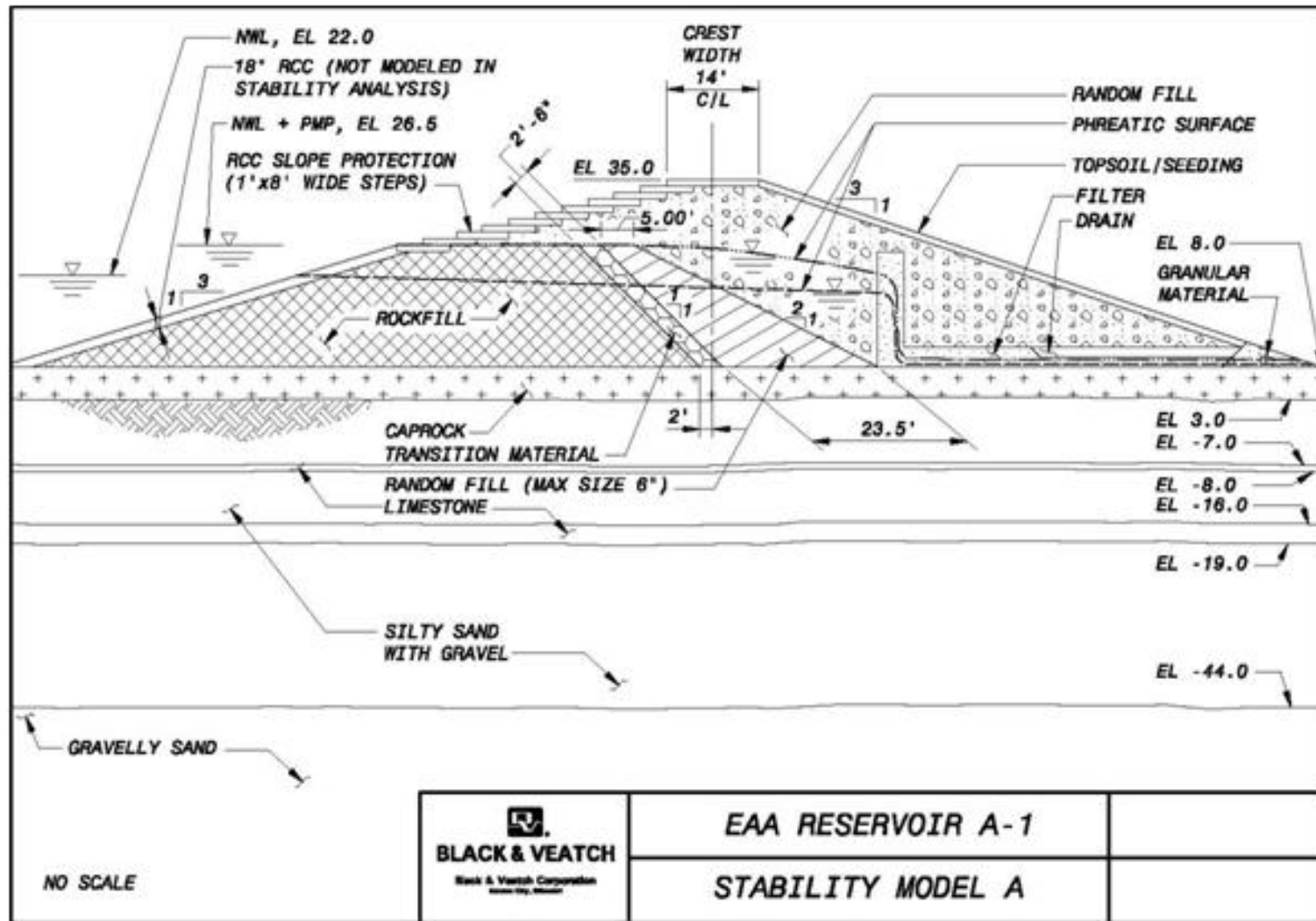


Figure 9 Stability Model B

